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13. ABSTRACT *(Maximum 200 words)*
BACKGROUND: A significant number of casualties in previous conflicts have died from extremity vascular wounds. A well-designed tourniquet could possibly have prevented these deaths. The initial objective of this study was to discover a working tourniquet system. The secondary objective became the development of such a tourniquet.
METHODS: Tourniquets presently available were identified. A tourniquet development project took place at the United States Military Academy. A patent search was also performed. No system appeared to work when placed by the casualty on themselves in a one-handed manner. A design team was created between WRAIR and Oregon State University. Criteria were developed from an 18 Delta Special Operations corpsmen questionnaire. Multiple tourniquet systems were conceptualized and built. Designs were narrowed down to 5 models: Strap (S), Bladder (B), Ratchet (R), Half-hitch (HH), and Ski boot Buckle (SB). Two designs were recieved from Special Operators: Red and CT. One multi-purpose bandage, the Emergency Bandage (EB) was tested. These tourniquet systems were taken to Navy SEAL corpsmen, who tested the devices on themselves. Success was determined by loss of peripheral pulse. A follow up questionnaire was completed. The Esmark bandage was later tested in our lab.
RESULTS: The R, B and Red units reliably occluded peripheral arterial blood flow with acceptable times. Other devices were notable for varied success rates. R was most preferred, followed by B. Esmark can successfully stop blood flow.
CONCLUSIONS: Most 18 Deltas carry a cravat or NSN 6515-00-383-0565, both of which are extremely difficult to place one handed and do not function reliably. Most tourniquets do not work within the confines of the 18 Delta criteria developed in this study. As they exist, R appears to be the best design for far forward application. B has the most potential for a "smart" system which automatically inflates/deflates. The EB, though not reliable as a tournquet, adapts well as a bandage/pressure bandage at multiple sites.The Esmark, although cumbersome, can work but is not superior to R or B.

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FOREWORD

This research was carried out under funding line 1160407BB. The Biomedical Initiative Steering Committee, United States Special Operations Command supported the tourniquet project. This group coordinates a number of research, as well as research and development, projects designed to enhance the abilities of Special Operations medics, corpsmen and pararescuemen to care for casualties in the Special Operations environment. The following research presented was performed through Combat Trauma Research, Department of Resuscitative Medicine at the Walter Reed Army Institute of Research, Washington, DC.

Naval Special Warfare Group One Medical, Coronado, CA, made this evaluation possible by creating teaching sessions that allowed the tourniquet assessments. Their efforts and the efforts of the evaluating Special Operations corpsmen are greatly appreciated.

Evaluation of Possible Tourniquet Systems For the Far Forward Setting

Introduction

Exsanguination was responsible for almost 50% of combat deaths in Viet Nam. Although approximately 80% of these individuals died from major vascular chest and abdominal wounds, around 20% exsanguinated from peripheral vascular injuries. These deaths were potentially easily preventable with timely application of a working tourniquet. In other words, a well-designed tourniquet could possibly have prevented 10% of combat deaths.

The initial objective of this project was to discover a working tourniquet system with the ability to stop arterial blood flow to the distal extremity. No systems were discovered which could be applied by the casualty himself/herself, using only one hand, and reliably occlude blood flow. The secondary objective became the development of a tourniquet system which fulfilled these criteria.

The goal was to discover existing tourniquet systems and then have the ultimate users, 18 Delta corpsmen and medics, determine which device(s) was (were) most appropriate for their environment.

Methods

The project began with identification of present tourniquets. The National Stock Number listing was first addressed showing two possible tourniquets for field use. Other available tourniquet systems, most useful for venous blood draws, were identified. A project with the United States Military Academy Engineering Department produced several belt-type tourniquets. Because all these systems were not felt to reliably occlude arterial blood flow when the casualty placed the tourniquet on himself/herself using only one hand, a patent search was performed. Although features of certain devices were good, no device appeared, as a whole, to be appropriate for the Special Operations environment. Tourniquet design was then started at the Walter Reed Army Institute of Research, Combat Trauma Research, and extended as a team was organized with Oregon State University, Department of Engineering. Criteria were established following a questionnaire completed by 18 Deltas regarding the desirability of certain features. Multiple systems were conceived, of which the most promising were built. These were narrowed down to approximately five systems. We were also able to obtain several

systems built by Special Operators. These final designs were taken to the ultimate users, 18 Delta corpsmen (Naval Special Warfare Group One) for testing and evaluation, after which they completed a questionnaire. See below for details.

The Project

Available Systems

The first step was to look at the national stock number list. Four tourniquets were listed, two of which were registered as pneumatic devices, one (NSN 6515-01-287-0607) at $5214 and the other (NSN 6515-00-383-0400) at $362. Their descriptions made it obvious that these units were not only expensive, but also large. Two tourniquets with potential were discovered and ordered. One, the blue rubber elastic system, using a piece of rubber and Velcro, NSN 6515-01-146-7794, is intended to function as a venous occlusion device used for blood draws and peripheral intravenous (IV) catheter placement. This particular item does not allow for arterial occlusion and may not work in the case of an arterial injury. It therefore did not get evaluated for possible field use. The second, the green cotton strap (figure 1), nonpneumatic NSN 6515-00-383-0565, is intended for field use in the event of a peripheral vascular injury. It soon became apparent that the green cotton strap could not reliably stop arterial flow, as assessed by palpation of distal peripheral pulses, even when others were applying the device. It could only function appropriately when used with a stick, as a windlass, and this only with another person applying it or if the casualty has a lower extremity wound.

The Emergency Bandage (figure 2), available from First Care Products, Israel, functions as a simple bandage, pressure bandage and/or tourniquet, also using the windlass technique. This bandage system is quite versatile and appeared to have the most potential of those tourniquets seen to this point. However, the potential problem remained difficult application by the casualty himself with unreliable arterial occlusion. This device was included in our 18 Delta evaluations because it appeared a very versatile device and to see if difficulty in one-handed use would be the case.

Other tourniquet systems, such as the red nylon elastic system (figure 3), were also discovered. However, these, like the blue elastic device, were only intended for venous occlusion. Although these could possibly stop slow venous bleeding, they would not reliably work in the face of an arterial injury.

West Point Project

The above findings led the author to believe that no ideal tourniquet systems were available which allowed an injured soldier to place the tourniquet on himself, reliably occluding their peripheral pulse. It was decided that such a system would have to be developed. The mechanical engineering students at West Point were tasked with the project. Brunkow C and Ramage J. Final Report, ME496. United States Military Academy, West Point, New York, 1996. This effort produced a belt-based tourniquet. However, disappointingly, their prototype's problem remained reliable occlusion of arterial blood flow.

WRAIR/Oregon State Project

It became apparent that new tourniquets would have to be developed. In addition, corpsmen/medics with tourniquet ideas were invited to submit their systems for a formal analysis. A contract was established with the Mechanical Engineering Department at Oregon State University. Together, the WRAIR and Oregon State University team would work to develop a number of tourniquet systems. The goal was to present the end users, 18 Delta corpsmen and medics, with a number of options which they could test and evaluate, reporting on which designs they preferred.

Desirable Characteristics

The first step was to identify which characteristics were felt to be important. A list of customer requirements was produced (Table 1). A number of Navy SEAL and Reconnaissance corpsmen ranked those features from 1 (most important) to 15 (least important). Table 2 provides the combined results. Primary concerns were to have a system actually stop blood flow, work on upper or lower extremities with quick application, be lightweight and compact, as well as have the ability to be occasionally released. Theses qualities were not seen in the tourniquet systems described above.

Patent Search

A patent search was performed to discover which systems might fulfill some or all of the previously described desirable characteristics. U.S. Patent 4, 870, 978 is shown in figure 4. The tourniquet consists of surgical tubing tied in knots at regular intervals. The tourniquet is applied by feeding the loose end through the opening of the loop end. Tightening occurs as the loose end is pulled, knots sliding through the constricted opening. Construction of this system revealed that, although it can at times prevent arterial flow, this tourniquet results in significant pain, and more importantly, underlying tissue damage.

U.S. Patent 4, 911,162 (figure 5) provides an example of some systems used to provide venous occlusion for blood draws and peripheral IV catheter placement. Elastic cord, like surgical tubing, is connected to a tab with a hole in it. The tourniquet tightens as the loose end of the tubing is pulled through the hole in the tab. Although this works well for blood draws, pulling tighter, necessary to stop arterial flow, will not reliably occlude all flow and causes significant pain and tissue damage.

Figure 6 shows U.S. Patent 4, 149, 540. This design consists of webbing, Velcro and a rectangular ring. The long end of the webbing is inserted through the ring and snugged. Further tightening takes place when the two ends of the webbing are pulled. Based on similar designs we worked with, this system will not allow consistent occlusion of arterial flow.

U.S. Patent 4, 516, 576 is shown in figure 7. A strap is drawn through a pinching device, much like a seat belt. Pressing the side of the unit activates a releasing mechanism. U.S. Patent 4, 640, 281 (figure 8) and U.S. Patent 4, 125, 115 (figure 9) operate using a ratchet type of action. Both appear to have multiple, complex parts.

Up to this point no tourniquet system existed fulfilling the customer requirement characteristics ranked by SEAL and Reconnaissance combat corpsmen, allowing for rapid one-handed placement on the upper, as well as lower extremities, stopping blood flow with a lightweight, compact device. Although no device was determined to be ideal, there were aspects of some which could be useful in creating a more ideal device for the Special Operations environment.

New Concept Development

A number of potential concepts were looked at for design development. Their sketches and descriptions follow. It would be from these that the final tourniquets would be built for 18 Delta evaluations. Recurrent findings included slipping around the extremity and inability to tighten devices enough when using simple belt-type designs in a one-handed fashion. Therefore, such systems would probably require an additional mechanical advantage to obtain the necessary tightening.

Figure 10 depicts the ribbed elastic strap concept. The tapered end of the device is fed through a slot in the connector. As the loose end is pulled through the connector, ribs prevent the band from releasing backwards. Any idea with similar rubber or plastic features would require significant effort and expenses to create molds when building

these prototypes. Once molds have been created, the cost is significantly reduced. Unfortunately, that follows once it is determined that a specific tourniquet system is desired.

Another concept, shown in figure 11, dealt with internal placement of a tourniquet system within the battle dress uniform. Four separate tourniquets would be built into the sleeves and legs. This system would require modification of Special Operator's uniforms. In addition, systems which would be unobtrusive enough not to affect operations, usually a webbing with D-ring and Velcro, were discovered to not reliably occlude arterial flow. Those designs which turned out to be reliable would appear to be just bulky enough to interfere with tasks. Although a uniform-integrated design might be feasible, such a tasking would necessitate extensive development as well as expenses.

To provide the additional mechanical advantage needed to make a simple belt system reliably occlude arterial flow we attached a simple ratchet system. The first type used came from Sidi, an Italian company that makes road and mountain bike shoes. Although it functioned, the ratchet was slightly small and difficult to lever. With the same concept a tourniquet that incorporated a snowboard binding ratchet was designed. Figure 12 illustrates the ratchet idea. With this system, the strap is placed over the injured extremity. Once snug, the ratchet is worked back and forth until the necessary tightening has occurred.

Figure 13 demonstrates an elastic strap and slide concept. A loop of elastic material runs its loose ends through a slide. A bite grip resides on the connected loose end. The casualty places the bite grip in his teeth and pulls back with his head. The available upper extremity pushes the slide down until it contacts the extremity. Gaining the necessary mechanical advantage is difficult using this technique.

Figures 14 through 18 illustrate a concept that centers on an inflatable bladder. In all cases the bladder is inflated until blood flow is stopped. This idea lends itself to the integrated uniform design. A single inflation source could be used for any of the four extremity tourniquets. The concept depicted in figure 14 utilizes a CO_2 cartridge as an inflation source. The concept shown in figure 15 inflates when a release pin is removed. Chemicals similar to those used in emergency life rafts would cause the tourniquet bladder to inflate. Using these inflation sources necessitates carrying additional cartridges or chemicals and limits how much inflation can be take place. In scenarios of prolonged extraction times, multiple inflations and reinflations could deplete the available pressure source. These bladder concepts would work nicely in "smart tourniquets" systems where the device automatically inflates and deflates at set intervals.

The Army Medical Research and Materiel Command have proposed development projects for such systems.

Using an inflation bulb, much like those on blood pressure cuffs or pressure infusers, allows an unlimited pressure source. Figures 16 through 18 show different bladder systems with an detachable pressure bulb. Multiple different widths may be constructed using Velcro and a rectangular ring for initially tightening prior to inflation.

Figure 19 reveals the compression ring concept made of a rigid band tightened by a ratchet and pawl mechanism. The device loosens by twisting the mechanism in the opposite direction used to tighten. Complexity and difficulty with getting the device into a compact form limit its usefulness.

The double loop concept consists of single strap and two connectors. Once slipped over the extremity, the exterior loop is tightened. Figure 20 illustrates this concept. The loose end of the outer loop must then be fastened. This could occur with a windlass, but that incorporates the difficulties found with such a system when attempting to place one-handed.

The half-hitch concept, shown in figure21, consists of webbing sewn around a rectangular ring on one end and webbing sewn to a plastic fastener. The short piece of webbing sewn to the fastener is also sewn onto the loop of webbing near the rectangular ring. The free end of the webbing runs under the fastener, through the rectangular ring and back through the fastener. In essence, tightening creates a pulley-like action in effort to create the additional mechanical action necessary with simple belt systems.

Lastly, figures 22 and 23 picture a simple webbing belt with a ski boot buckle. Macro adjustment occurs when the loop is initially tightened snug through a fastener. The final tightening takes place when the buckle is latched and finally closed. The ski boot buckle provides the additional mechanical advantage needed to occlude blood flow after the simple belt is tightened. Unfortunately, this additional action creates significant skin pinching and pain when activated.

Narrowing Down the Concepts

Table 3 lists the potential advantages and disadvantages of the described concepts. Looking at these factors, applying the customer requirements previously mentioned and determining which would be overly complex and expensive to produce, the potential designs were narrowed down five:

Ribbed elastic band
Bladder
Ratchet
Half-hitch
Ski boot buckle

These were the designs which were felt to have the best opportunity of fulfilling the customer requirement within the confines of this research and development project. Development efforts would focus on constructing finalized prototypes for evaluation by Special Operations corpsmen and medics.

Prototype Design

A more focused prototype development process now took place. The ribbed elastic strap necessitated building from scratch as no similar commercial products could be identified. An aluminum mold had to be prepared before the materials could be poured. The ribbed free end of the device required a material of different elasticity than that of the connector. Therefore, the finalized product is constructed of two different pourable compounds, one making up the majority of the ribbed tongue portion and the other making up the majority of the connector portion. Figure 24 shows a photograph of the completed strap. Weight and dimensions are reported in Table 4.

The bladder concept went through a number of modifications. The main idea centered on bladder surrounded by protective nylon material with a bulb inflator. Different widths and lengths were constructed and custom sized bladders fitted. The initial snugging of the device works with a rectangular ring and Velcro. Additional mechanical advantage is gained with inflation of the bladder by the bulb. Multiple widths, bladders and inflation sources could be adapted to this design. The weight and dimensions of the small bladder model, the one tested by the 18 Deltas, are found in Table 4. This model is seen photographed in figure 25.

The ratchet design utilizes the simple belt concept but incorporates a ratchet to gain the mechanical advantage necessary for occlusion of arterial blood flow. Multiple fasteners and ratchets could be used. One of the designs, photographed in figure 26, uses webbing and a buckle, the same one seen on the NSN cotton strap, but also includes a ratchet(from Burton snowboards) within the loop. Initial tightening is performed through the buckle followed by final ratchet tightening. A second design, not pictured but similar, uses webbing and a plastic fastener with a K2 snowboard binding. Multiple ratchets are available. The design was narrowed down to those seen on snowboard

bindings due to simplicity and ability to take a beating. Decreasing the length of the ratchet tongue could further reduce already acceptable weight and dimensions. The photograph demonstrates the ratchet tourniquet opened, as well as packed .

The half-hitch concept looks almost like the cotton strap (figure 27). The photograph shows webbing, sewn to a rectangular ring, sewn to a short piece of webbing connected to a buckle (same as buckle on NSN cotton strap), which feeds through the ring and back out the buckle. Tightening creates a pulley-like action, rather than the straight pull performed with the cotton strap.

The fifth design operates with a ski boot-type buckle providing the mechanical advantage after the initial tightening of a strap through a fastener. Figure 28 provides an example. Difficulties with fine tuning adjustment and significant pinching problems limited this device.

Functional prototypes of these described prototypes were constructed. Four proved to perform well by reliably occluding arterial blood flow as assessed by palpation or Doppler auscultation of peripheral pulse. Repeated pinching prevented pursuit of the ski boot buckle concept. Multiple variations of these five concepts were built. However, those shown in the photographs are the configurations which were tested by Special Operations corpsmen and medics.

Submitted Prototypes

Two ideas came in from outside sources. The first, called red due to its red webbing, arrived from a Special Forces medic. The concept focuses on the ratcheting provided by a cargo strap (Figure 29). The entire unit ratchets from its center as one or two of the ends are manipulated, drawing in the looped webbing.

The second submission came from the SEAL community. The unit, named CT for its maker, consists of nonelastic webbing which is macroadjusted using a plastic fastener. A small (approximately 1") portion of the loop is elastic webbing through which 550 cord runs. A buckle connected to the cord functions as a windlass. After twisting, the buckle tucks into one of two small loops to prevent unwinding. The photograph in figure 30 shows one of the models tested.

Addendum Tourniquet

After data collection had been completed, British soldiers made the author aware of their intent to have men carrying the elastic Esmark bandage for the purposes of tourniquet application. Figure 31 shows a photograph of an Esmark bandage. This thin rubber elastic device is typically used prior to orthopedic surgery as an aid to internally exsanguinate the extremity. The arm or leg is held up in the air and then wrapped by this elastic strip to push as much blood as possible out of the extremity. The Esmark is removed after a proximal pneumatic tourniquet is inflated in order to reduce arterial flow. The idea is to have as bloodless a surgical field as possible. Although 18 Delta data collection had taken place, we ran lab and medic tests. This information is reported below.

Special Operations 18 Delta Testing

Methods

Navy SEAL corpsmen from Group One performed evaluations and testing for the two submitted designs, the four that we developed and the Emergency Bandage. These 18 Deltas received a short overview of the project, reported customer requirements driving the designs and the tourniquets themselves. They familiarized themselves with the devices prior to testing. Testing of the seven different prototypes occurred in random order. Fifteen Special Operations corpsmen were timed in the placement of each device on one of their lower extremities, as well as their dominant upper extremity (an injury to this arm being worst case scenario). Timing started with initiation of placement and ended when the corpsman felt he had tightened the tourniquet adequately. The corpsmen were restricted to using only their nondominant arm to place a tourniquet on a presumed dominant upper extremity injury. Palpation and/or Doppler auscultation of peripheral pulses (radial artery in arm, dorsalis pedis artery in foot) determined success (loss of pulse) versus failure (no loss of pulse). Following the testing, the Special Operations corpsmen completed a questionnaire regarding prior use of tourniquets, what they are using now and their assessment of the tested devices (Table 5).

Results

The Bladder successfully occluded upper extremity (UE) (15/15) and lower extremity (LE) (13/13) arterial flow in 100% of placements. Averages times were 26.7 seconds (sec) for UE and 21.1 sec for LE. Table 6 shows percentage successful placement and times for the prototypes tested. The Ratchet successfully occluded UE flow 92.9% (13/14) of the time in an average of 20.6 sec. LE flow was stopped successfully by 84.6% of evaluators in 25.0 sec. Success with the CT was comparatively

reduced at 55.6% for the UE and 22.2% for the LE, with average overall average times of 71.1 sec and 41.7 sec, respectively. Average successful times are meaningless due to the small amount of success with this device. The Emergency Bandage successfully prevented UE arterial flow in 3 out of 10 attempts (30%) and LE arterial flow in 3 out of 11 attempts (27.3). Overall placement times were increased at 137.6 sec for the UE and 99.9 sec for the LE. Again, average successful times are without meaning secondary to the lack of success. The Strap lead to UE occlusion in 42.9% (3/7) with overall average time of 33.5 sec and LE occlusion in 60% (3/5) with overall time of 25.83 sec. RED worked on the UE in 14 out of 15 UE attempts (93.3%) in 30.4 sec and on the LE in 9 out of 12 LE attempts (9/12) in 26.4 sec. Although Half-Hitch times were small (18.1 sec UE and 23.6 sec LE), it was much less successful with UE arterial occlusion occurring in 38.5% (5/13) and LE arterial occlusion occurring in 1 out of 11 (9.1%).

One way analysis of variance was used to compare statistical significance of times. When comparing UE placements, the Bandage was significantly slower than all tested devices and CT slower than all others, except the Bandage. Of the more successful tourniquets, RED was slower than the Ratchet. When comparing devices for LE placement, the more successful devices did not significantly differ in time of placement.

The 18 Deltas responded to questions asking them to rank the devices from 1 (best) to 7 (worse) regarding which of the devices they would choose to take with them if deploying the day of the evaluation and also to rank the devices regarding their potential future development. These results can be seen in Table 7. Based on the averages the choices remained the same for use now as well as thoughts of potential development of the devices. Ratchet was ranked first, followed by the Bladder, Half-Hitch, Red, Emergency Bandage, CT and finally the Strap.

The paragraph below lists a compilation of comments regarding perceived advantages and disadvantages of the systems. Many thoughts recurred so will therefore be listed here only one time.

Bladder

Simple, quick, works

Bulky, ? problems w/ Velcro and sand, possibility of puncture

Strap

No good comments

Heavy, big, binds skin, too hard to use

CT

Good design if width increased

Need 2 hands, multiple parts, hard to manipulate, we already carry something similar, too complicated

Red

Works well

Hard to loosen, pinches, bad in salt water

Ratchet

Highly effective, best idea yet, works well, simple, easy, quick

Question durability, loud, pinches

Half-Hitch

Light, easy, simple

Does not stop blood flow, does not occlude

Bandage

Multi-purpose, good bandage, good pressure bandage, great device

Difficult to place on self, takes too long to place as tourniquet, not too good as tourniquet

When asked about which device they would carry today, responses varied. Ratchet and bladder were most often commented, as well as half-hitch. Ratchet and bladder were most often stated when asked which device they would recommend noncorpsmen carry.

Conclusions

Presently, most Special Operations carry the cravat or cotton strap as a tourniquet. Both of these devices require the use of a windlass to effectively stop arterial blood flow. Fortunately, most of the evaluators in our study had not applied a tourniquet in the field (2/15). The cravat and cotton strap do not fulfill the customer requirements created by the 18 Deltas we surveyed. In this study, windlass designs largely failed when having to place the tourniquet on oneself in a one-handed manner as well as when used with two hands. Not only were they unsuccessful, but they took more time. Windlass techniques can only succeed, under these requirements, if they incorporate a way in which to prevent the untwisting that usually occurs while attempting to tighten.

When considering tourniquet systems, one should first ask if the device actually occludes blood flow. Most systems do not work within the confines of the requirements listed in Table 2, developed by our own Special Operations corpsmen. Therefore, *when interpreting our data, success should be assessed prior to looking at placement times.* Those placement times are meaningless if the system does not occlude arterial flow. Simplicity and size are meaningless if the tourniquet cannot occlude arterial flow.

The Bladder succeeded 100% of the time in our study. Simplicity and ease of use contributed to its efficiency. It also rated as the number two preferred device. Quick placement times compare favorably to other devices and are legitimate due to its high level of success. This is the most comfortable of the systems and probably has the least potential for underlying tissue damage. Size should be reduced. Our particular prototype, covered in thick Velcro, could be built with more durable and less bulky covering material and a different fastening. This would reduce size, increase resistance to puncture and allay fears of failure in a sandy environment. Slightly less than half of evaluators reported that they would carry the Bladder today. The Bladder has the most potential for use as a "smart tourniquet" that can self-inflate and self-deflate to certain levels at specified time intervals. This type of a system is most beneficial for prolonged extraction scenarios.

Red, the cargo strap device submitted by a Special Forces medic, works well in stopping arterial flow, as seen by its relatively high rate of success. Placement times are therefore believable and acceptable. This device rated in the middle as fourth, despite being fairly successful in our study, due to weight, difficulty with release and the multiple metallic parts. Potential dysfunction following a salt water swim raises the most concern about packing Red.

The Strap involves too much weight and size for its effectiveness. Many corpsmen refused to test with this device. Success was not even marginal. During our study, one of these was torn in half (see figure 32). As a result it ranked last in both rankings. The Strap, as it presently exists, holds no application for the Special Operations environment.

There should be significant concerns over devices such as the Half-Hitch. This device was highly ranked, number 3, and fully a third of 18 Deltas said they would carry this device today. The Half-Hitch rates so well because it is simple, lightweight, small and quick to apply. However, as it presently exists, it works no better than the cotton strap. Times are inconsequential when only 1/11 (LE placements) or 5/13 (UE placements) can make it work. The major concern centers on the significant number of

failures for both UE and LE placement. Like the cotton strap, it will require a windlass, to truly perform its intended function.

Downfalls of windlass designs have been discussed. The two devices incorporating this technique in our study were no exception. The CT often untwisted while attempting to place it in a one-handed manner. Placement times reflect this trouble. Worse yet, a large number of attempts were unsuccessful. Use of the CT is not recommended. The Emergency Bandage, as a tourniquet, suffers from the same problems. Occlusion of arterial flow occurred infrequently. However, the multi-purpose potential as a simple bandage and pressure bandage which can adapt to multiple wounds sites on the body gives the FDA-approved Emergency Bandage significant potential for the Special Operations, as well as conventional military environment. One should not rely entirely on its ability to function as a tourniquet, without having a backup plan.

The Ratchet system was rated number one. High success rate and quick application times were noted. Simplicity, light weight, compactness and ease of one-handed placement are characteristics of this design. Easy release and retightening also make this device attractive in the face of long extraction times. Modifications of the ratchet tongue length could further reduce size. The Ratchet system appears to be the best tourniquet design of those tested when considering far forward potential.

The Esmark Bandage, rubber elastic Ace-type bandage, deserves some mention. The 18 Deltas did not test this device as the authors were unaware of this application at the time of testing. Information reported comes from evaluation in the WRAIR lab. Measurements and weight are noted in Table 4. This thin rubber elastic bandage, approximately 8-9 feet long unstretched, comes in a roll as pictured in figure 31. Reliable arterial occlusion was seen with UE placement times of 60-75 sec and LE times of 40-60 sec. Difficulty with one-handed application often occurred. Troublesome unraveling frequently delayed placement, as did problems with attempting to secure the tail end. However, if presented with the option of any NSN tourniquet or the Esmark, the Esmark should be carried. This bandage provides a cheap, readily available tourniquet. However, it is not felt to be superior to the Ratchet or Bladder if these are available.

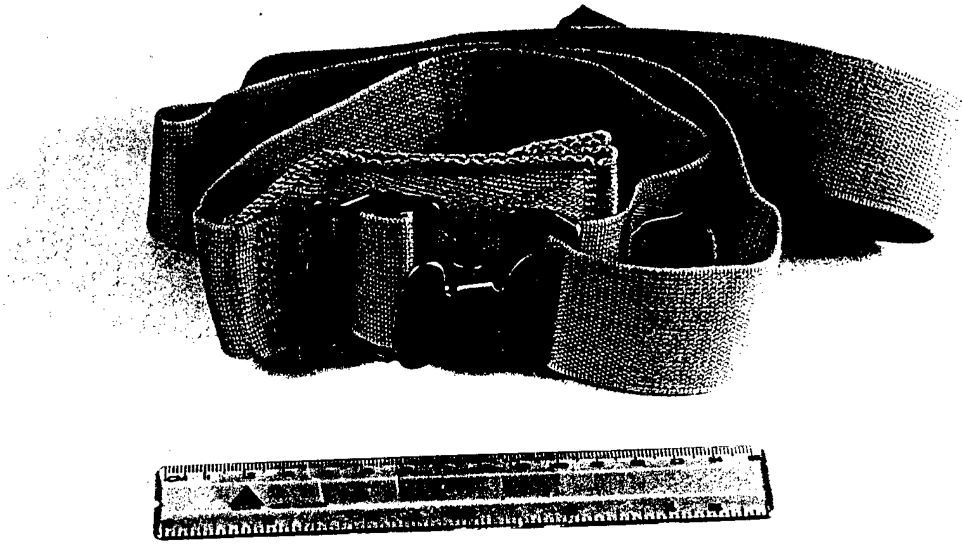

Figure 1: The Cotton Strap

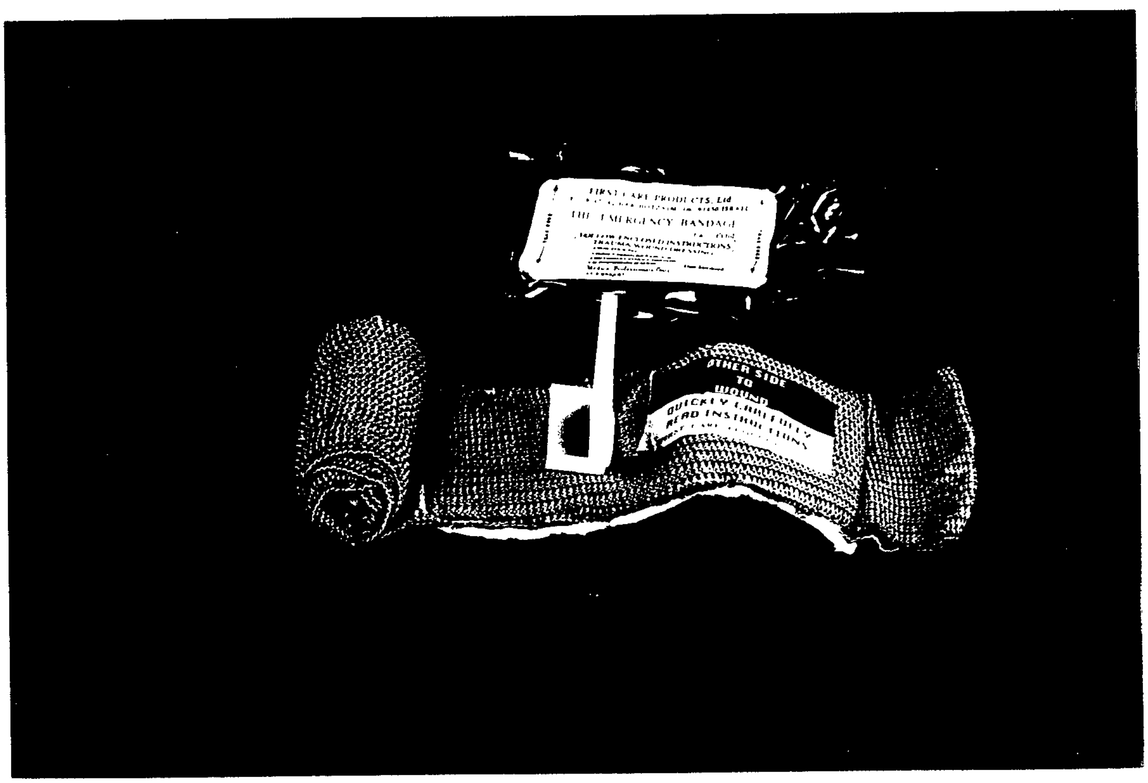

Figure 2: The Emergency Bandage

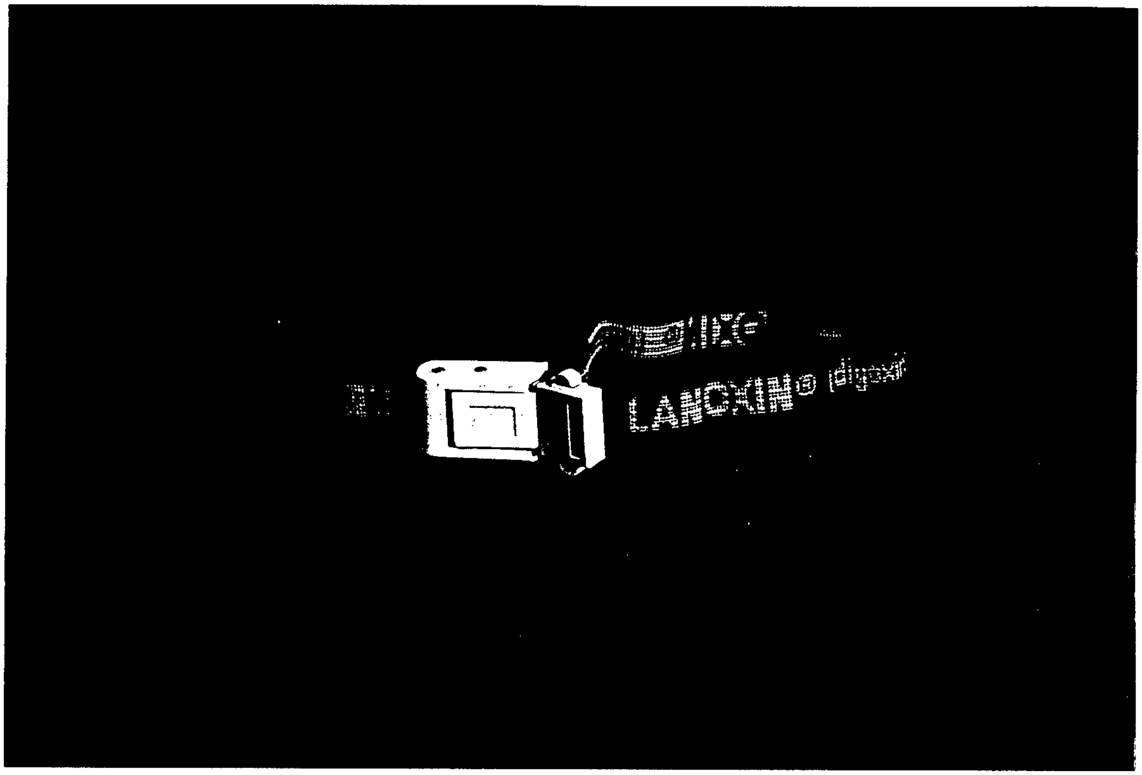

Figure 3: Red Nylon Elastic Tourniquet

Figure 4: U.S. Patent 4, 870, 978 (knotted surgical tubing)

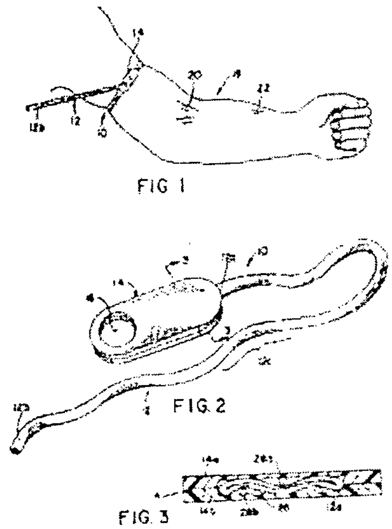

Figure 5: U.S. Patent 4, 911, 162 (surgical tubing and tab)

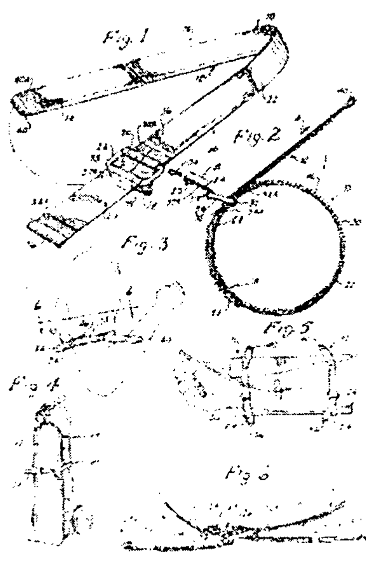

Figure 6: U.S. Patent 4, 149, 540 (double-ended webbing)

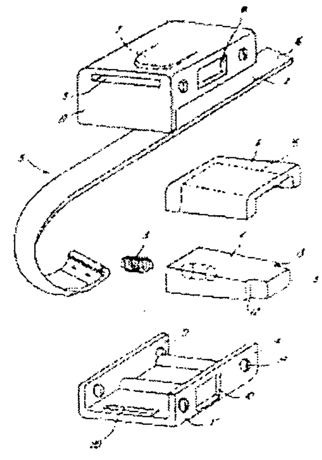

Figure 7: U.S. Patent 4, 516, 576 (seat belt-like)

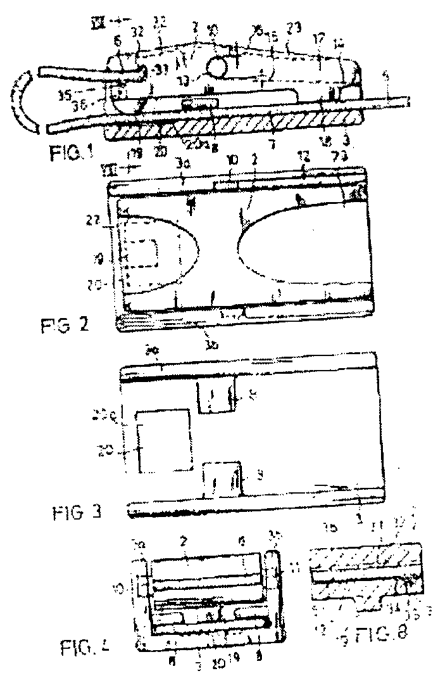

Figure 8: U.S. Patent 4, 640, 281 (ratchet type)

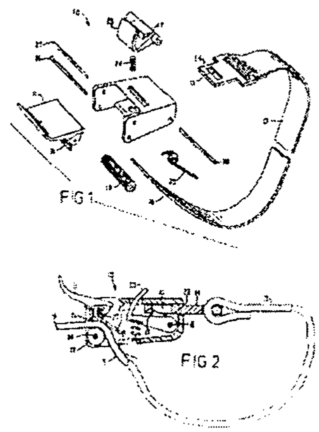

Figure 9: U.S. Patent 4, 125, 115 (ratchet type)

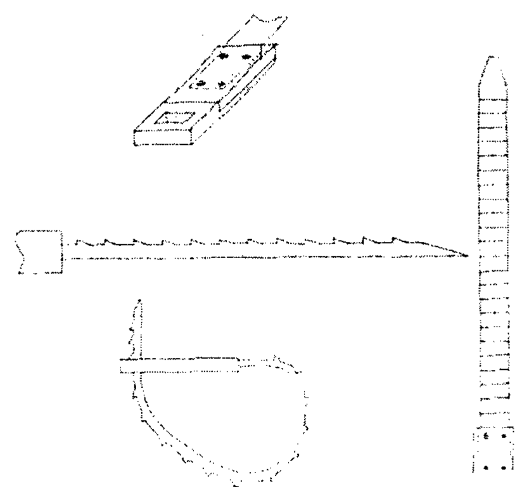

Figure 10: Ribbed Elastic Strap

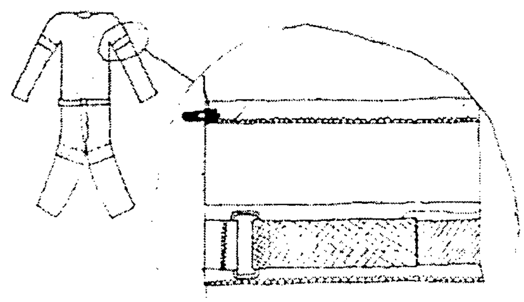

Figure 11: Internal Uniform

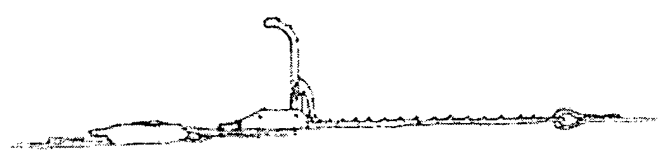

Figure 12: Ratchet

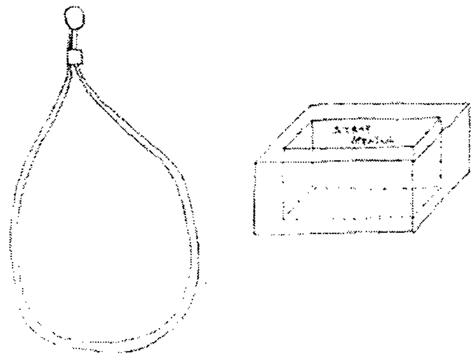

Figure 13: Elastic Strap and Slide

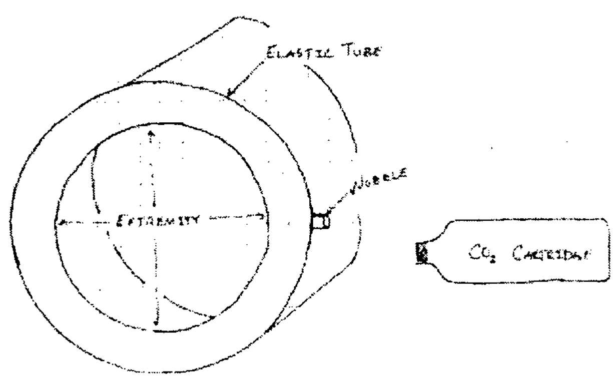

Figure 14: Bladder with CO_2 Cartridge

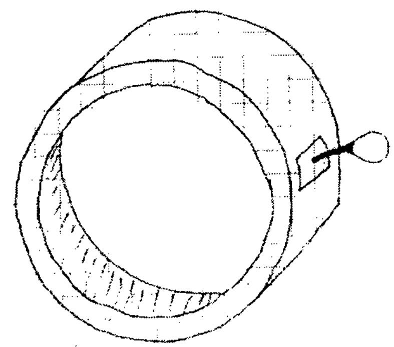

Figure 15: Bladder and Release Pin

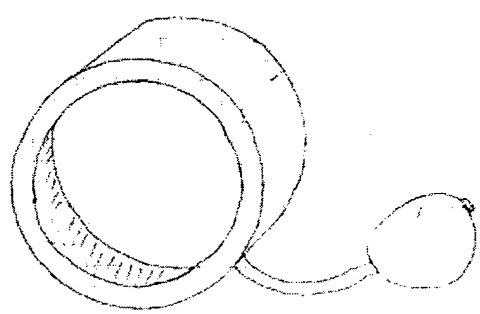

Figure 16: Bladder and Inflator Bulb

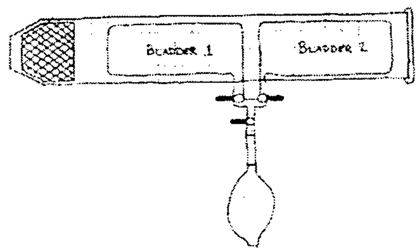

Figure 17: Double Bladder

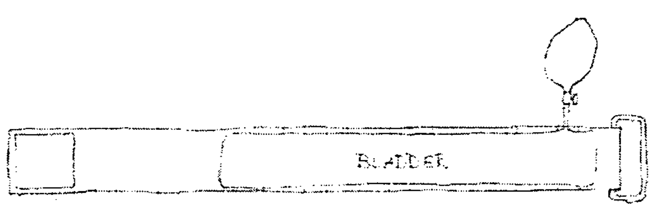

Figure 18: Bladder with Velcro and D-ring

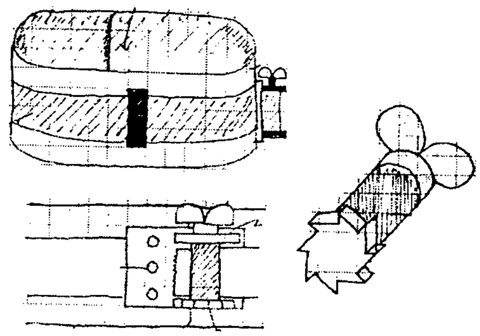

Figure 19: Compression Ring

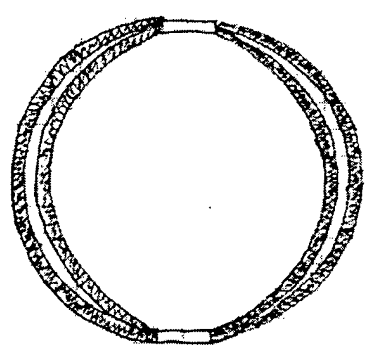

Figure 20: Double Loop

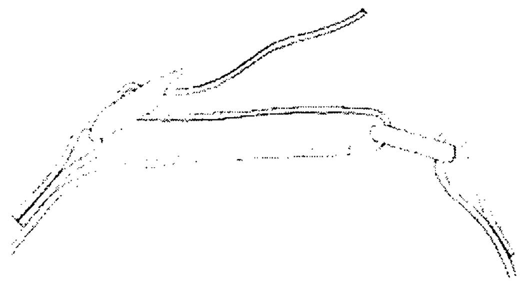

Figure 21: Half-Hitch

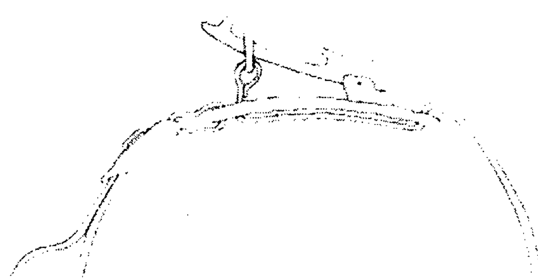

Figure 22: Ski Boot Buckle

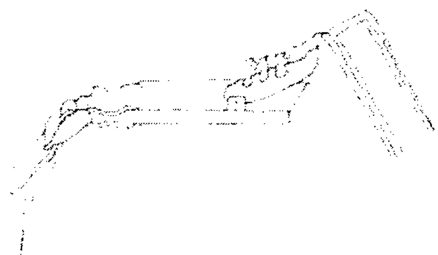

Figure 23: Ski Boot Buckle

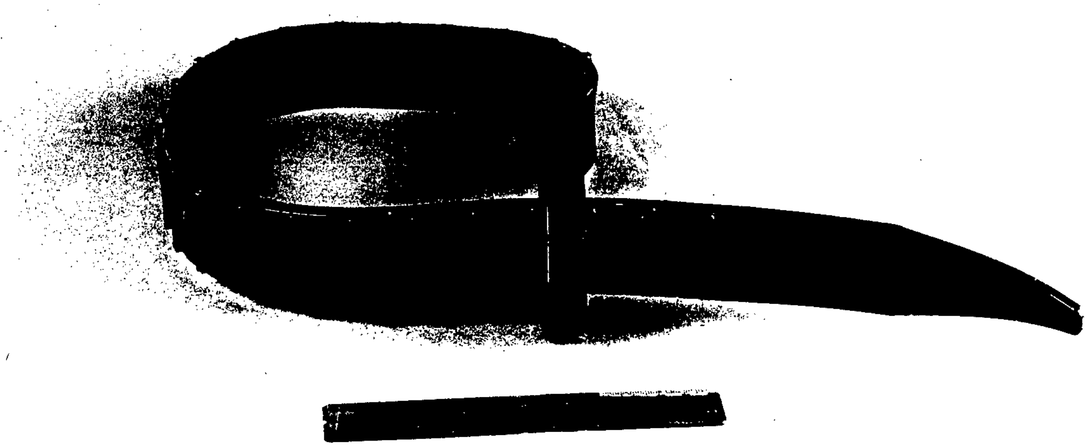

Figure 24: The Strap

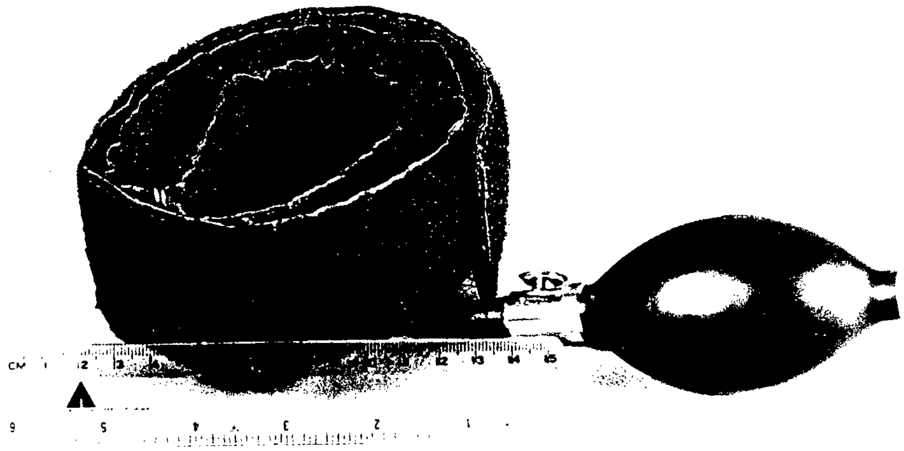

Figure 25: The Bladder

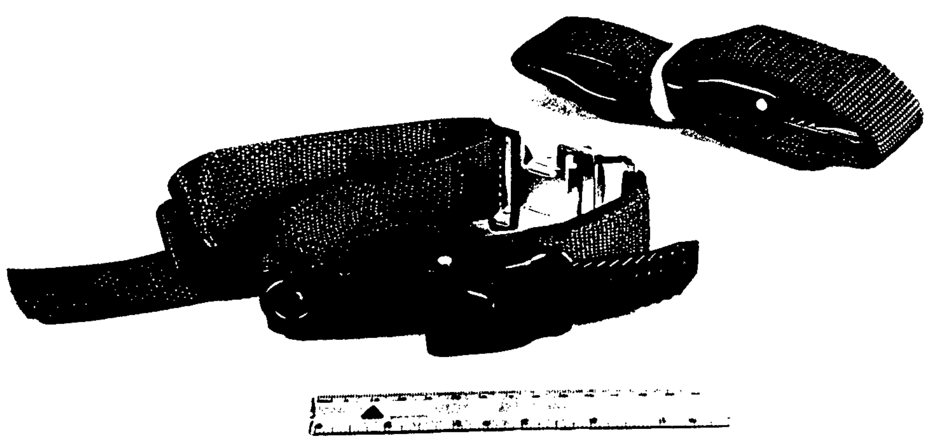

Figure 26: The Ratchet

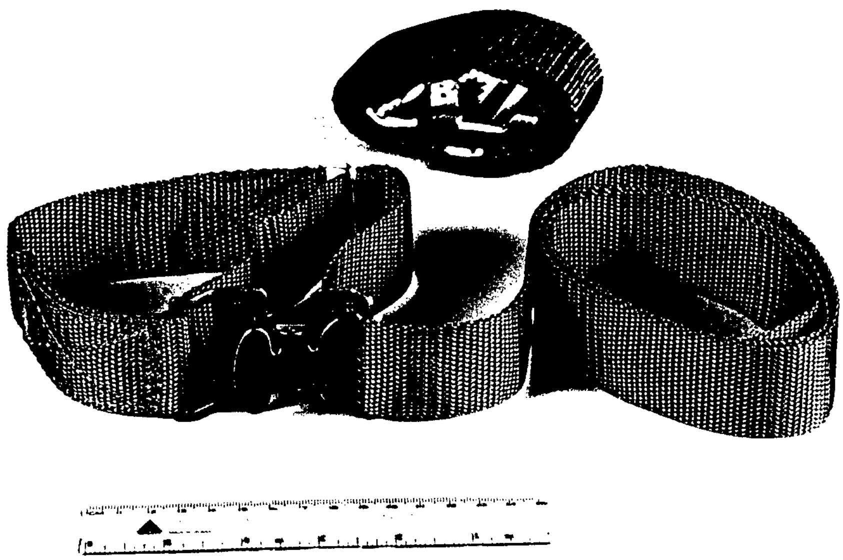

Figure 27: The Half-Hitch

Figure 28: The Ski Boot Buckle

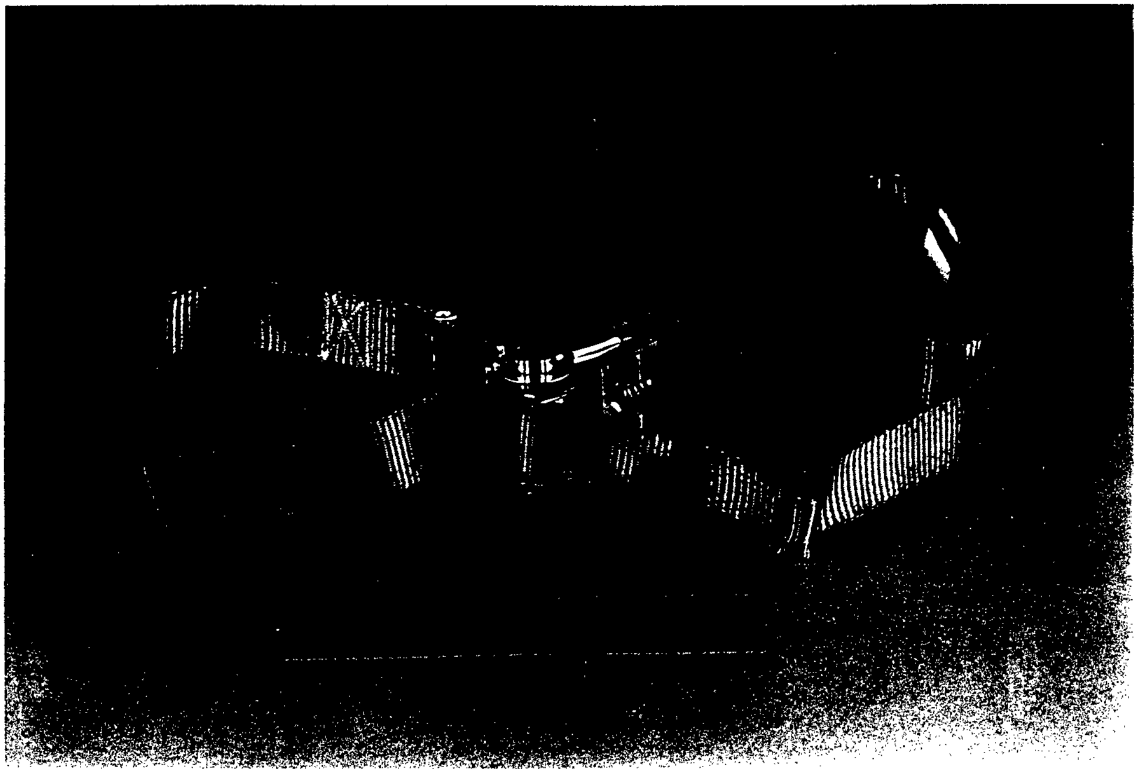

Figure 29: Red (cargo strap)

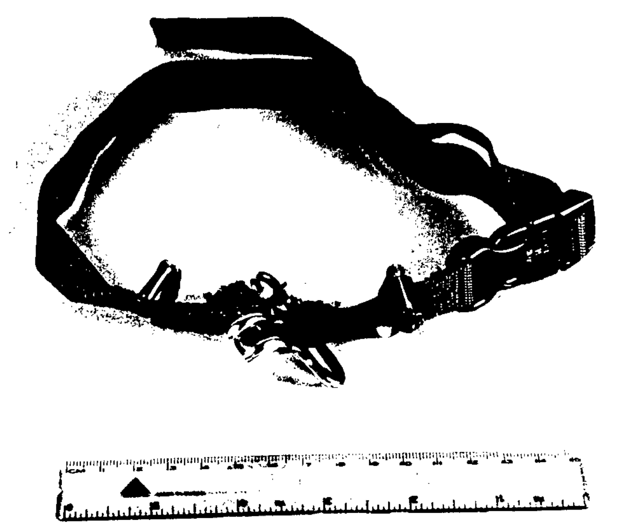

Figure 30: CT

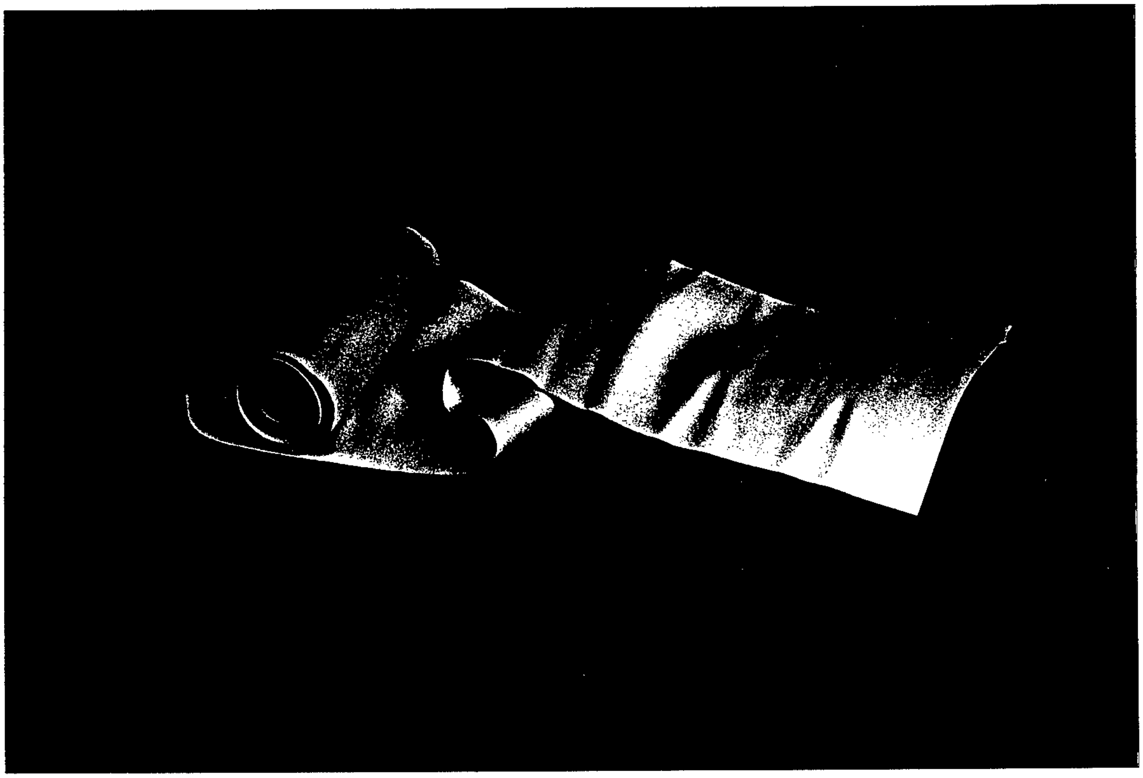

Figure 31: Esmark Bandage

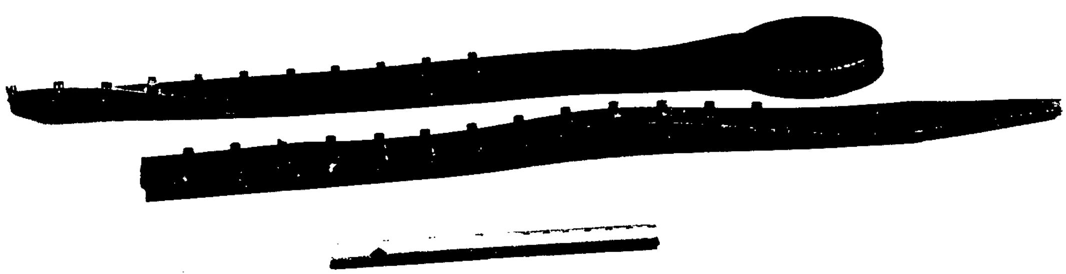

Figure 32: Damaged Strap

Table 1: Customer Requirements Survey

CHARACTERISTICS	RANKING
Stops blood flow	
Lightweight	
Compact	
Multipurpose	
One-handed operation	
Easy access	
Use for upper and lower extremities	
Quick application	
Removable	
Comfortable	
Subdued coloring	
Inexpensive	
Easy to manufacture	
Over 1 inch in width	
No mechanical parts	

Table 2: Compiled Customer Requirements Survey

CHARACTERISTICS	RANKING
Stops blood flow	1
Lightweight	2
Compact	4
Multipurpose	8
One-handed operation	7
Easy access	9
Use for upper and lower extremities	5
Quick application	3
Removable	6
Comfortable	14
Subdued coloring	11
Inexpensive	12
Easy to manufacture	13
Over 1 inch in width	10
No mechanical parts	

Table 3: Concepts and Potential Advantages/Disadvantages

CONCEPTS	ADVANTAGES	DISADVANTAGES
Cotton Strap	Available on NSN list Light Simple	Need windlass to stop arterial flow Difficult self placement
Blue Rubber Elastic	Available on NSN list Simple	Only stops venous flow
Emergency Bandage	Light Simple Multipurpose	Uses windlass for tourniquet Difficult self placement
Red Nylon Elastic	Light	Only stops venous flow Multiple cheap components
Belt	Simple Inexpensive	Does not stop arterial flow Requires windlass to work
US Patent 4,870,978 (Knotted surgical tubing)	Light Simple Easy to manufacture	Pain Tissue damage
US Patent 4,911,162 (Surgical tubing and tab)	Light Simple Easy to manufacture	Pain Tissue damage Does not stop arterial flow
US Patent 4,149,450 (Double ended webbing w/ velcro and D-ring	Light Simple	Does not reliably stop arterial flow
US Patent 4,516,576 (seat beat-like)	Easy release	Complex construction Bulky
US Patent 4,640,281 (ratchet type)	Easy tighten Easy release	Complex construction Bulky
US Patent 4,125,115 (ratchet type)	Easy tighten Easy release	Complex construction Bulky

Table 3: Concepts and Potential Advantages/Disadvantages (continued)

CONCEPTS	**ADVANTAGES**	**DISADVANTAGES**
Ribbed Elastic Strap	Simple Easy to manufacture	Difficulty with tightening
Internal Uniform	Quick Everyone has one Light	Need to alter uniform Interference with duty ? ability to occlude flow
Ratchet	Light Simple	Potential pinching Several components
Elastic Strap and Slide	Light Simple Easy to manufacture	? ability to occlude flow
Bladder	Simple Easy to apply Reliable occlusion "smart tourniquet" possible	Potential damage of components Could be bulky
Compression Ring	Simple Easy to apply	Cumbersome Damage by environment Construction expense
Double Loop	Light Simple Inexpensive	? ability to occlude flow may need windlass
Half-Hitch	Light Simple Inexpensive	Possible confusion in which loop to place extremity
Ski Boot Buckle	Light Simple	Pinching

Table 4: Tourniquet Weights and Dimensions

TOURNIQUET	WEIGHT (GRAMS)	DIMENSIONS[1] (L" X H" X W")
Strap	287	6 x 2 x 1.5 (tongue) 6 x 2 x 3 (at connector)
Bladder	138 alone 207 w/ large bulb 168 w/ small bulb	3.5^2 x 2
Ratchet	145 (Burton) 123 (K2)	6 3/4 x 1 3/4 x 1 7/8 6 3/4 x 1 1/2 x 1 3/4
Half-Hitch	107	4 x 1 3/4 x 1 7/8
Ski Boot Buckle	112	4 3/4 x 2 x 1 1/4
CT	26	2 x 1 x 3/4
Red	236	4 5/8 x 1 3/4 x 1 7/8
Cotton Strap	93	3 3/8 x 1 1/2 x 2 1/4
Emergency Bandage	81	4 1/2 x 1 1/2 x 2 3/4
Esmark Bandage	129	1 $3/8^2$ x 4

[1]Maximum dimensions are reported for the device as it would be packed

[2]The bladder and Esmark bandage would be packed in a circular form, so diameter is reported along with width

TABLE 5

Tourniquet Project - Special Operations
Corpsmen/Medic/PJ Questionnaire

Corpsmen/Medic ________________ Training (i.e. 18 Delta) __________________

1. What do you carry for a tourniquet now? What are its main advantages/disadvantages?

2. Have you ever had to place a tourniquet before? YES NO
   If so, how many times? What did you use? How did you apply it?

3. If you had to use a tourniquet today, rank your order of preference (1 best to 7 least liked) for each model.

Bladder CT Ratchet Bandage Strap RED Half-hitch

4. Based on the *potential* of the concept, rank each of the tourniquets in order of preference (1 most promising to 7 least promising)

Bladder CT Ratchet Bandage Strap RED Half-hitch

5. Please make comments regarding advantages/disadvantages and/or suggested changes for each of the systems as well as other potential uses for the devices.

Bladder

Ratchet

Strap

Half-hitch

CT

Bandage

RED

6. Which, if any, of the evaluated models would you carry today? If you believe none of these should be carried, what will you carry otherwise?

7. Which models, if any, would you recommend a noncorpsman/nonmedic carry? If you believe the noncorpsman should not carry any of these, what do you think he should carry?

Table 6: Success and Times of Placement

DEVICE	UE SUCCESS PERCENT	UE AVERAGE TIME SUCCESSFUL PLACEMENT (SEC)	UE AVERAGE OVERALL TIME (SEC)	LE SUCCESS PERCENT	LE AVERAGE TIME SUCCESSFUL PLACEMENT (SEC)	LE AVERAGE OVERALL TIME (SEC)
Bladder	100 (15/15)	26.7	26.7	100 (13/13)	21.1	21.1
CT	55.6 (5/9)	69.7	71.0	22.2 (2/9)	37.7	41.7
Ratchet	92.9 (13/14)	20.6	21.4	84.6 (11/13)	25.0	24.4
Bandage	30.0 (3/10)	129.0	137.6	27.3 (3/11)	56.8	99.9
Strap	42.9 (3/7)	42.8	33.5	60.0 (3/5)	22.4	25.8
RED	93.3 (14/15)	31.1	30.4	75.0 (9/12)	26.4	26.7
HH	38.5 (5/13)	15.1	18.1	9.1 (1/11)	14.3	23.6

Table 7: Ranking of Devices (from 1 best to 2 worst)
average of the rankings is reported

DEVICE	RANKING TODAY	RANKING POTENTIAL FOR FUTURE APPLICATION
Bladder	2.79	2.97
CT	5.11	4.61
Ratchet	1.70	1.97
Bandage	4.54	4.47
Strap	6.50	6.79
RED	3.93	3.89
Half-Hitch	3.50	3.13